

STRENGTH BEHAVIOUR OF COLUMN STUDS IN PREFABRICATED WALL
PANELS USING COLD-FORMED STEEL

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To my beloved family...

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ABSTRACT

A full-scale experimental study on the strength behaviour of individual studs and column studs in a prefabricated wall panel is presented in this report. The individual stud and the panel are made of cold-formed steel sections with a dimension of 3 m height, and 3.15 m height and 1.5 m width respectively. At the moment, the British Code has not provided adequate detail design to account the load capacity of a cold-formed steel column stud in a prefabricated wall panel. The structural performances of column stud therefore need to be obtained through the experimental investigation. A total of five specimens were tested in pure axial compression until failure. The specimens consist of three specimens with one type of lipped C-channel designated here as S350CT1, S350CT2 and S350CT3, one specimen of I-section, D350CT1 and one specimen of wall panel, W350CT1. Comparison between experimental values for column stud in the wall panel and experimental values for the individual studs were made. Experimental values for the individual studs were also compared with the theoretical values computed based on BS 5950-Part 5:1998 Code of practice. All individual studs which were subjected to pure axial compression, except the S350CT1, failed due to flexural buckling (FB) mode, with a substantial visible permanent deformation and without significant torsional buckling. S350CT1 failed due to shearing of the bolts in the bolted connection. From the investigation, it can be concluded that the selection of section geometries affect the failure stress capacity of individual studs dramatically. All individual stud failure loads obtained experimentally are in good agreement with the predicted values. As for the prefabricated wall panel, it was found that a flexural buckling and local buckling had occurred in the wall panel as the wall panel reaching the failure, and subsequently the ultimate load.

ABSTRAK

Kajian ujikaji berskala penuh terhadap kelakuan dan kekuatan stad individu dan stad tiang di dalam panel dinding pasang siap dibentangkan di dalam laporan ini. Stad individu dan panel ini dibina menggunakan keratan keluli terbentuk sejuk dengan ukuran ketinggian 3 m untuk stad individu, dan 3.15 m tinggi dan 1.5 m lebar untuk panel. Ketika ini, *British Code* tidak menyediakan butir-butir rekabentuk yang lengkap untuk pengiraan beban keupayaan bagi stad tiang menggunakan keluli terbentuk sejuk di dalam panel dinding pasang siap ini. Oleh itu, ciri-ciri dan kelakuan struktur stad tiang perlu diperolehi melalui kajian ujikaji. Sebanyak lima spesimen telah diuji di bawah daya paksi mampatan sehingga mencapai kegagalan. Lima spesimen ini terdiri daripada tiga spesimen yang menggunakan keratan berbibir berbentuk C, ditandakan sebagai S350CT1, S350CT2 dan S350CT3, satu spesimen yang menggunakan bentuk keratan-I, D350CT1, dan satu lagi spesimen panel dinding, W350CT1. Perbandingan antara keputusan ujikaji makmal untuk stad tiang di dalam panel dinding dan keputusan ujikaji makmal untuk stad individu kemudiannya dibuat. Keputusan ujikaji makmal untuk stad individu juga dibandingkan dengan nilai secara teoritikal yang diperolehi daripada pengiraan berpanduan *BS 5950-Part 5:1998 Code of practice*. Kesemua stad individu yang dikenakan daya paksi mampatan, kecuali S350CT1, gagal di dalam mod lengkukan lenturan, dengan kerosakan kekal yang kelihatan dengan ketara dan tanpa lengkukan kilasan. S350CT1 telah gagal disebabkan oleh kegagalan bolt secara ricihan di dalam sambungan secara bolt. Daripada ujikaji, dapat disimpulkan bahawa pemilihan bentuk keratan amat mempengaruhi keupayaan kegagalan tegasan bagi stad individu. Kesemua nilai beban kegagalan secara ujikaji untuk stad individu selaras dengan nilai yang dijangkakan. Untuk panel dinding pasang siap, keputusan ujikaji menunjukkan lengkukan lenturan dan lengkukan tempatan kelihatan apabila panel dinding mencapai kegagalan.

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LIST OF SYMBOLS

a^b	- Thickness of flat test piece (for coupon specimen)
A	- Area of a cross-section or gross area
A_{eff}	- Effective cross-sectional area
A_i	- Area of each element
A_n	- Net area of a section
A_t	- Tensile stress area of the bolt or area at the bottom of the threads
α	- Coefficient of linear thermal expansion or - Factors for member in compression
b	- Flat width of an element or - Width of the parallel length of a flat test piece (for coupon specimen)
b_{eff}	- Effective width of a compression element
b_{eu}	- Effective width of an unstiffened compression element
b_g	- Gripped end width (for coupon specimen)
b_j	- Width of flat elements (mid-line dimension)
b_1, b_2	- Mid-line dimensions of the respective elements assuming rounded corners are replaced with intersections of the flat elements
B	- Overall flange width
BL	- Overall lipped depth
C_w	- Warping constant of a section
d	- Nominal diameter of the bolt or - Diameter of the screw
d_e	- Distance from the centre of a bolt to the end of the connected element in the direction of the bolt force
d_s	- Head of screw or washer diameter

D	- Overall web depth
D_c	- Depth of the compression zone of the web, taken as the distance from the neutral axis of the gross cross-section to the compression element
D_w	- Section depth or twice the depth of the compression zone
e	- Distance between the centre of a bolt and any edge of the connected member or - Shear centre position as shown in Table D.1 BS 5950-Part 5
e_s	- Distance between the geometric neutral axis and the effective neutral axis of a section
E	- Modulus of elasticity of steel
E_t	- Tangent modulus
f	- Local buckling stress
f_c	- Compressive stress on the effective element
f_{cr}	- Critical local buckling stress
f_{pr}	- Proportional limit
F_s	- Longitudinal shear force
F_y	- Yield point
G	- Shear modulus of steel
I_x, I_y	- Second moment of area of a cross-section about the x and y axis respectively
J	- St Venant torsion constant of a section
K	- Buckling coefficient of an element
L_c	- Parallel length (for coupon specimen)
L_E	- Effective length of a member about the critical axis
L_g	- Length between gripped area (for coupon specimen)
L_o	- Original gauge length (for coupon specimen)
L_t	- Total length of test piece (for coupon specimen)
m	- Number of flat elements
M_c	- Moment capacity of a cross-section
M_i	- Distance from centre of each element to the bottom flange
n	- Number of all 90° corners
N_i	- Distance from centre of each element to the web
p_c	- Compressive strength

p_{cr}	-	Local buckling stress of an element
p_o	-	Limiting compressive stress
p_s	-	Shear strength obtained from Table 11; BS 5950-Part 5
p_t	-	Tension strength obtained from Table 11; BS 5950-Part 5
p_y	-	Design strength of steel
P_{bb}	-	Bearing capacity of bolt
P_{bs}	-	Bearing capacity of connected elements
P_c	-	Buckling resistance under axial load
P_{cs}	-	Short strut capacity
P_E	-	Elastic flexural buckling load (Euler load) for a column
P_{Ex}, P_{Ey}	-	Elastic flexural buckling load (Euler load) for a column about x and y axis respectively
P_{fs}	-	Shear capacity of screw by testing
P_{ft}	-	Tensile capacity of screw by testing
P_s	-	Shear capacity of bolt or Shear capacity of screw
P_t	-	Tension capacity of bolt or Tensile capacity of screw
P_T	-	Torsional buckling load of a column
P_{TF}	-	Torsional-flexural buckling load of a column
P'_c	-	Buckling resistance after consider M_c and e_s
Q	-	Factor defining the effective cross-sectional area of a section
r_{cy}	-	Radius of gyration of one channel
r_i	-	Radius of corner (mid-line dimension)
r_o	-	Polar radius of gyration of a section about the shear centre
r_x, r_y	-	Radius of gyration of a section about the x and y axis respectively
s	-	Longitudinal spacing of interconnections
S_o	-	Original cross-sectional area of the parallel length (for coupon specimen)
S_v	-	Spacing between bolts or screws
S_x, S_y	-	Plastic modulus about the x and y axis respectively

t	-	Net material thickness or
	-	Minimum thickness of the connected material
t_1, t_2	-	Thicknesses of element widths b_1 and b_2 respectively
t_3	-	Thickness of the member in contact with the screw head
t_4	-	Thickness of the member remote from the screw head
ν	-	Poisson ratio
w	-	Width of the plate
x_o	-	Distance from the shear centre to the centroid of a section measured along the x axis of symmetry
X_1, X_2	-	Distance from centroid to left and right edge of the section measured along the x axis of symmetry respectively
\bar{X}, \bar{Y}	-	Horizontal and vertical position of the neutral axis from the web or lipped and bottom flange respectively
X_i, Y_i	-	Distance from centre of each element to the centre of cross-section in horizontal and vertical direction respectively
Y_s	-	Material yield strength
Y_1, Y_2	-	Distance from centroid to top and bottom edge of the section measured along the y axis of symmetry respectively
Z_x, Z_y	-	Section modulus about the x and y axis respectively
λ_x, λ_y	-	Slenderness ratio about the x and y axis respectively
η	-	Perry coefficient

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

A wall is a continuous vertical structure, which is thin relative to its length and height. External walls help to provide shelter against our environment such as wind, rain and the daily and seasonal variations of outside temperature to its location, for reasonable indoor comfort and internal walls divide buildings into rooms or compartments. To provide adequate shelter a wall must have sufficient strength and stability to be self-supporting and to resist the loads from roofs and upper floors. To differentiate the structural requirements of those walls that carry lateral and axial loadings (the loads from roof and upper floors in addition to their own weight) from those that are freestanding and carry only their own weight, the terms load bearing and non load bearing are used [1]. Other functions of walls are to enclose the space within it and to divide that space to provide privacy, security and equable conditions for storage and operations for occupants in the building. The commonly accepted specific requirements of a wall are stability, strength, resistance to weather and ground moisture, durability, fire safety, good thermal properties and resistance to airborne and impact sound, security and aesthetics [2].

Nowadays, the use of prefabricated wall panel in the construction industry has become a very common trend. The need to increase production efficiency, to save materials and to respond to the changing demands of building, users is leading to increase the use of prefabrication. Advantages of using prefabricated wall panel is to ensure consistency of quality as the wall frames have been properly engineered to meet specific load, wind bearing and bracing requirements, to include savings cost and time and easier site inspection as well as greatly improved in design details and during fabrication of the units. For instance, prefabricated and preassembled construction has been successfully applied to the standard public housing blocks throughout the 1990s. Prefabricated wall systems are manufactured in the factory, trucked to a construction site, lifted into position on a building using a crane, and anchored in place. The current market for prefabricated wall system is diverse and extensive, ranging from precast concrete wall panels to utilized glass and metal curtain wall systems [3].

Masonry, timber and reinforced concrete have traditionally been used for walls, but cold-formed steel continues to grow in popularity due to its structural and material advantages. In comparison with these conventional construction materials, steel is inherently recyclable and incurs much less cost to the environment (in terms of energy consumption and pollution) during its processing. The use of cold-formed steel has been more prevalent as well as in commercial or community applications because they are lighter than traditional concrete. A cold-formed steel wall panel internally or externally normally consists of top and bottom tracks, studs, braces (depending on the strength requirements) and the studs to track were connected together using bolts, welds, screws, pins or rivets (Figure 1.1). The studs were connected to horizontal tracks top and bottom, and sheathed on one or two side with board, which can be assembled together on site or manufactured in the factory. Steel frame should be fully integrated with both the external and internal wall panel systems as well as the floor systems so that they are mutual supporting. This lead naturally to consideration of stresses skin design [4].

Many companies involved in the construction industry are small or medium sized and so their ability to industrialise their methods may be limited. There is also increasing pressure to develop construction systems that are more sustainable. Buildings should be designed to use materials from renewable sources that minimise transportation costs, can be easily disassembled and reused. One area where there is an opportunity to develop system that may suit a variety of different sized organisations and improved the sustainability of construction is the use of cold-formed steel prefabricated wall panels as it is very cheap [5].

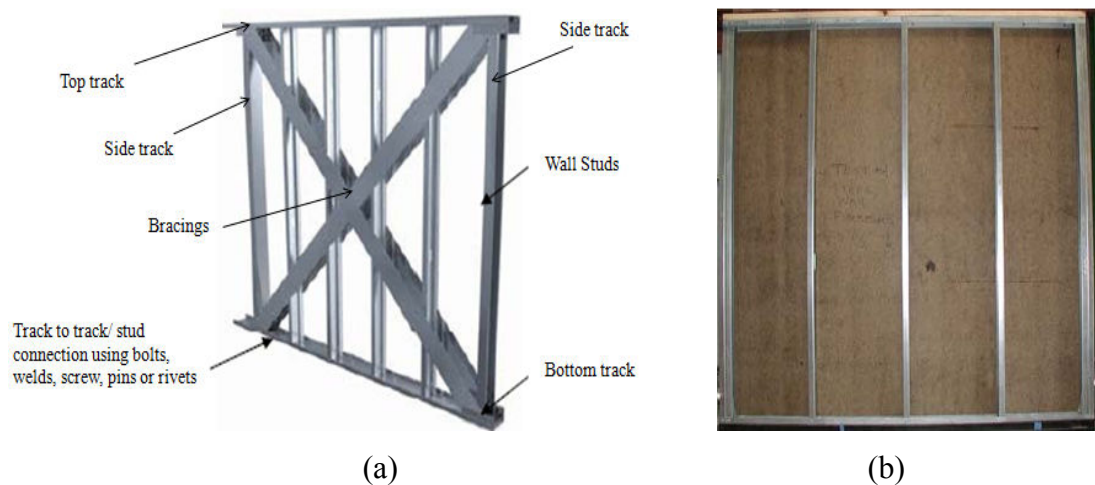


Figure 1.1 Typical wall assemblies a) wall panel with bracing, b) wall panel with one side sheathing

1.2 Problem Statement

When the demand of low capital cost, easy and simple fabricated structure component, new techniques that suitable for both factory and site construction, erection that allows for deconstruction and recycling, and a very light structure component; is on the rise, prefabricated wall is one of the solution. The cheapest and suitable material is cold-formed steel that can be used as a main structure or column studs in a wall panel. Typically, the cold-formed steel cross-sections mostly used as

column studs are single C-channel and I-section made of back-to-back C-channel. The strength of the wall is depending on the overall buckling of main structure, column stud. At the moment, the British Code [6] has not provided adequate detail design to account the load capacity of a cold-formed steel column stud in a prefabricated wall panel. The structural performances of column stud therefore need to be obtained through the experimental investigation.

For these reason, an experimental study was carried out to evaluate the possibility behaviour of four individual stud specimens using two different section geometries (C-channel and I-section) and column studs using C-channel in one full-scale prefabricated wall panel. Then the relation between individual stud and column stud will be observed.

1.3 Aim and Objectives

The aim of this study is to determine the strength behaviour of the individual stud and column studs in prefabricated wall panel made by cold-formed steel. The main objectives of this study are:

- a) To investigate the buckling behaviour by determining the ultimate load of both; the individual stud and column studs in a prefabricated wall panel subjected to compression.
- b) To obtain the overall behaviour in terms of the failure modes of prefabricated wall panel.
- c) To observe the insensitivity of the individual studs to the geometry of the sections.

- d) To compare the individual stud test failure loads with the predicted load values, calculated based on BS5950-Part 5:1998 Code of practice for the design of cold-formed sections [6].
- e) To correlate the results of the individual stud test to the results of the column stud in prefabricated wall panel test.

1.4 Scope

The scopes of this study will cover both the experimental and theoretical investigation of cold-formed steel section subject to compression;

1. The specimens for individual stud test were included three C-channel sections and one I-section, and were tested in simply supported condition for compression failure.
2. Determination of the design yield strength of cold-formed steel sections using tensile coupon test.
3. Determination of the axial compression capacity of cold-formed steel sections experimentally and theoretically.
4. The wall panel constructed with 3.15 m height and 1.5 m width.
5. Column studs will be the focus of the study for prefabricated wall panel experimental.